ALGEP:

Concept Study for an Autonomous Lunar Geophysical Experiment Package

– Progress Report –

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Outline

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- Apollo ALSEP
- ALGEP Design Assumptions & Drivers
- Baseline Design
  - Instrument Suite
  - ALGEP Architecture
  - Thermal, Power, Command/Data and Telecom Subsystems
- Operational Scenarios
- Summary and Conclusions

Science Background

JPL ALGEP

- ALGEP was conceived to address the major science goals articulated by the NRC related to understanding the lunar interior:
  - What were the details of the Moon's formation? (e.g., composition of the accretion disk, degree of melting, late bombardment, …)
  - How did the Moon differentiate? (e.g., depth of melting, fractionation processes in the magma ocean, core formation, …)
  - How did it subsequently evolve? (e.g., partial melting and basalt generation, core solidification and dynamo generation, subsolidus convection, …)
- Answering these questions requires the following geophysical measurements:
  - Seismic measurements
  - Heat flow determinations
  - Magnetic field monitoring (induction studies)
  - Precise tracking (rotational dynamics)
- A more thorough discussion of the science rationale was presented at LPSC XXXIX.

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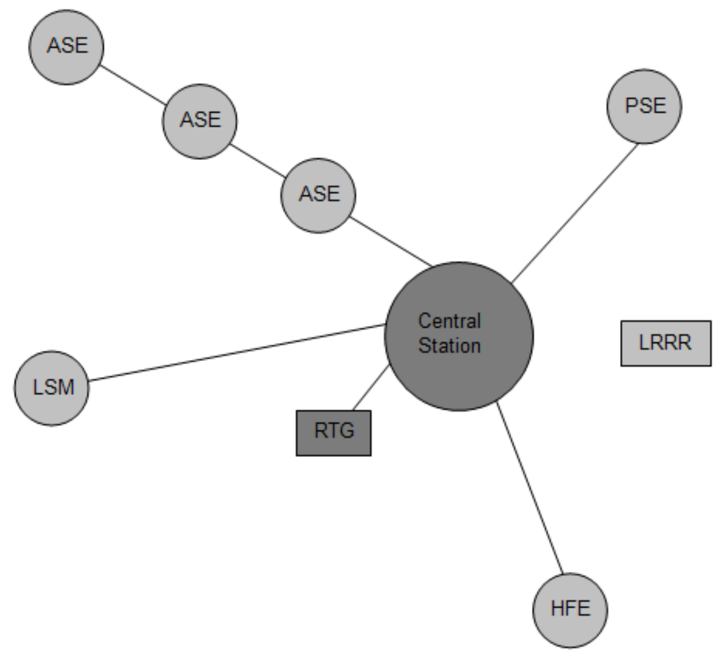
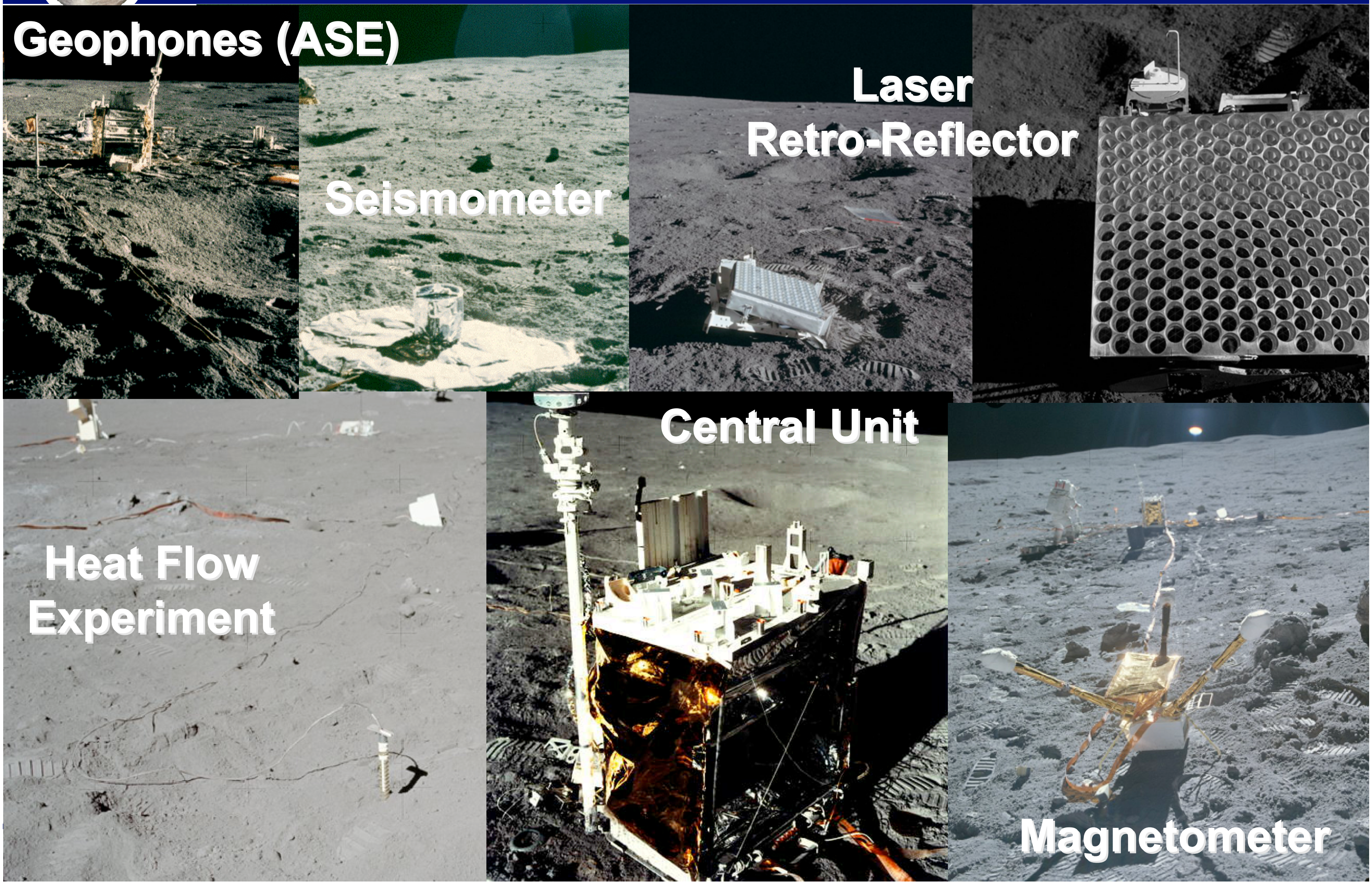
Apollo Lunar Surface Experiments Package (ALSEP)

- Deployed on Moon during Apollos 12, 14-17 by astronauts (1969-1972)
- Instrument complement included:
  - Active Seismic Experiment (ASE)
  - Passive Seismic Experiment (PSE)
  - Lunar Surface Magnetometer (LSM)
  - Heat Flow Experiment (HFE)
  - Laser Ranging Retroreflector (LRRR)
- Power was provided by a Radioisotope Thermoelectric Generator (RTG).
- RTG enabled continuous instrument operation, including night.
- Designed for 1 year of operation, actual operations continued for more than 7 years.
- Data acquisition was terminated in 1977.



"Hub and spoke" configuration of ALSEP packages. Instruments connected to the Central Station through power and data lines.

Apollo Era ALSEP Instrument Suite



Desired Improvements Over ALSEP

ALGEP

- Better quality science data
  - Improved sensitivity, resolution, S/N, etc.
- Longer design lifetime
  - 6 years or greater
- Simplified operations
  - Store-and-forward telemetry architecture
- No nuclear materials
- Portability and ease of deployment
  - Minimize cabling
  - Reduced package mass
- Astronaut safety
  - Trip hazards
  - Nuclear material handling

ALGEP Design Assumptions

- Lifetime: 6 years ± 2 years
- Continuous instrument operation
  – Exception: Seismic Sounders will operate intermittently for 2 weeks during the daylight
- Lunar surface temperature range: -170°C to 125°C
- Package designed to operate in any lunar location astronauts can reach
  – Worst case considered power required at equatorial region where night is ~14 days
- Baseline design assumes solar power (no nuclear)
- Package will be designed to be as wireless as possible for easy deployment and astronaut safety
- Direct-to-Earth communication through Deep Space Network (DSN)
- Science data latency is not a driver

Design Drivers

- Night-time operations is the strongest driver
  - ~14 Earth-day night at equatorial region
  - Seismometer and magnetometer both require continuous operations through the night
  - Lunar temperature environment drives both power and thermal subsystem design
- Seismology is data volume driver
  - Passive seismometer accumulates 100s Mbit per 24-hour period, several Gbit during lunar night
  - Seismic Sounder instrument acquires ~0.7 Gbit/measurement
- Astronaut safety/activity constraints drive package configuration and deployment methods

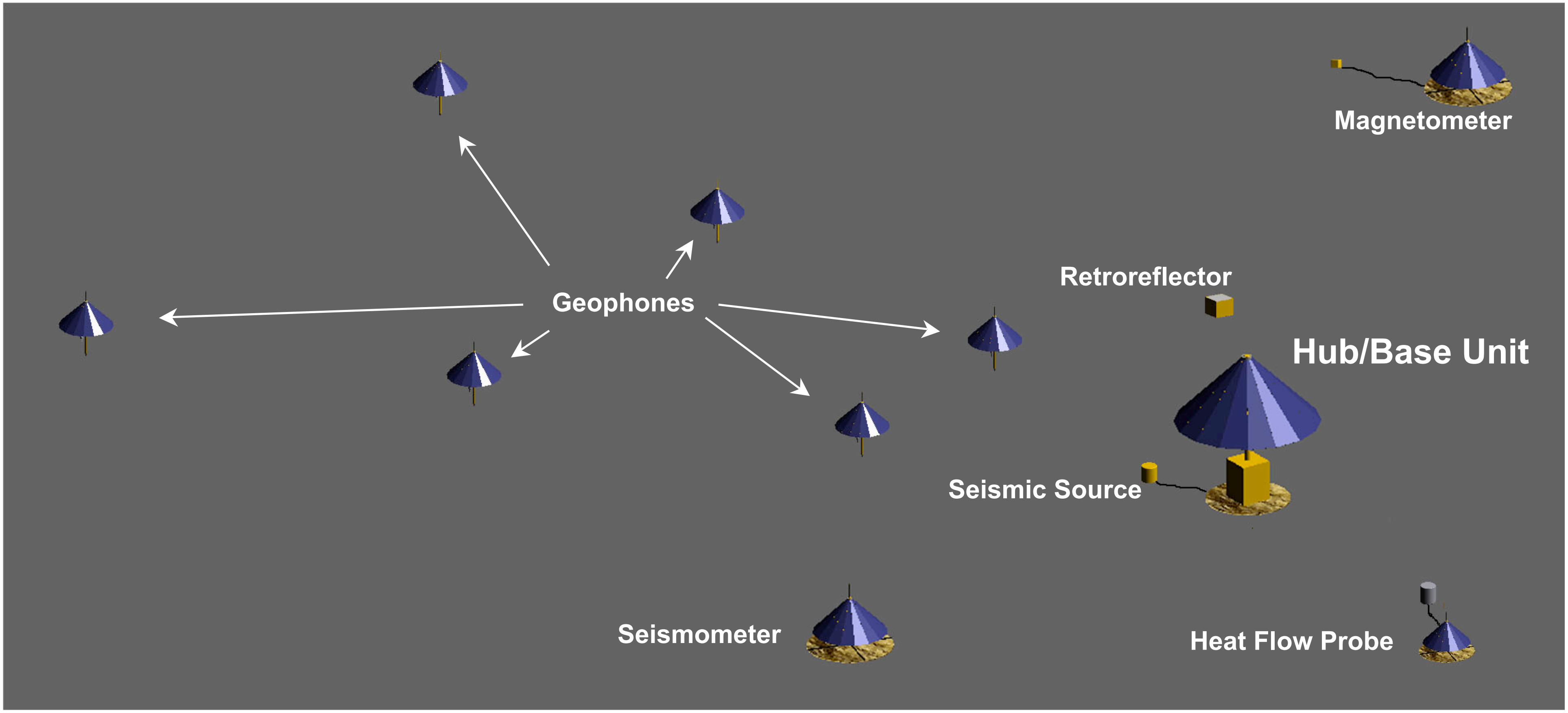
ALGEP Instrument Complement

Instrument	Instrument for Astronaut Baseline	Required Operational Lifetime	Mass	Average Power	Data Rate	Duty Cycle
Seismometer	SEIS (IPGP)	6 years	4.5 kg	1.5 W (lower sampling rate many allow for power reduction for night)	2 – 9 kbps	100% (lower sampling rate during night)
Magnetometer	LMAG (UCLA)	6 years	0.655 kg (includes electronics & cabling)	0.550 W	2.5 kbps	100%
Heat Flow Probes	HP^3 (DLR)	6 years	1.6 kg	5.7 W Conductivity 2.2 W Temperature 11 W Hammering	~40 Mbit (data volume over experiment)	~5-8% (After initial hammering emplacement, 5 min per hr for temperature measurements)
Laser Ranging	Retroreflector	6 years	~5 kg	Passive, no power required.	N/A	N/A
Seismic Sounders	Seismic Sounder (CRUX)	2 weeks (daylight only)	4.5 kg (includes 6-12 sensors and source)	1.6 W Receiver Sensors have own power supply to be supplied with instrument.	7200 kbps (few seconds per measurement)	several hundred measurements over first lunar day

ALGEP Architecture

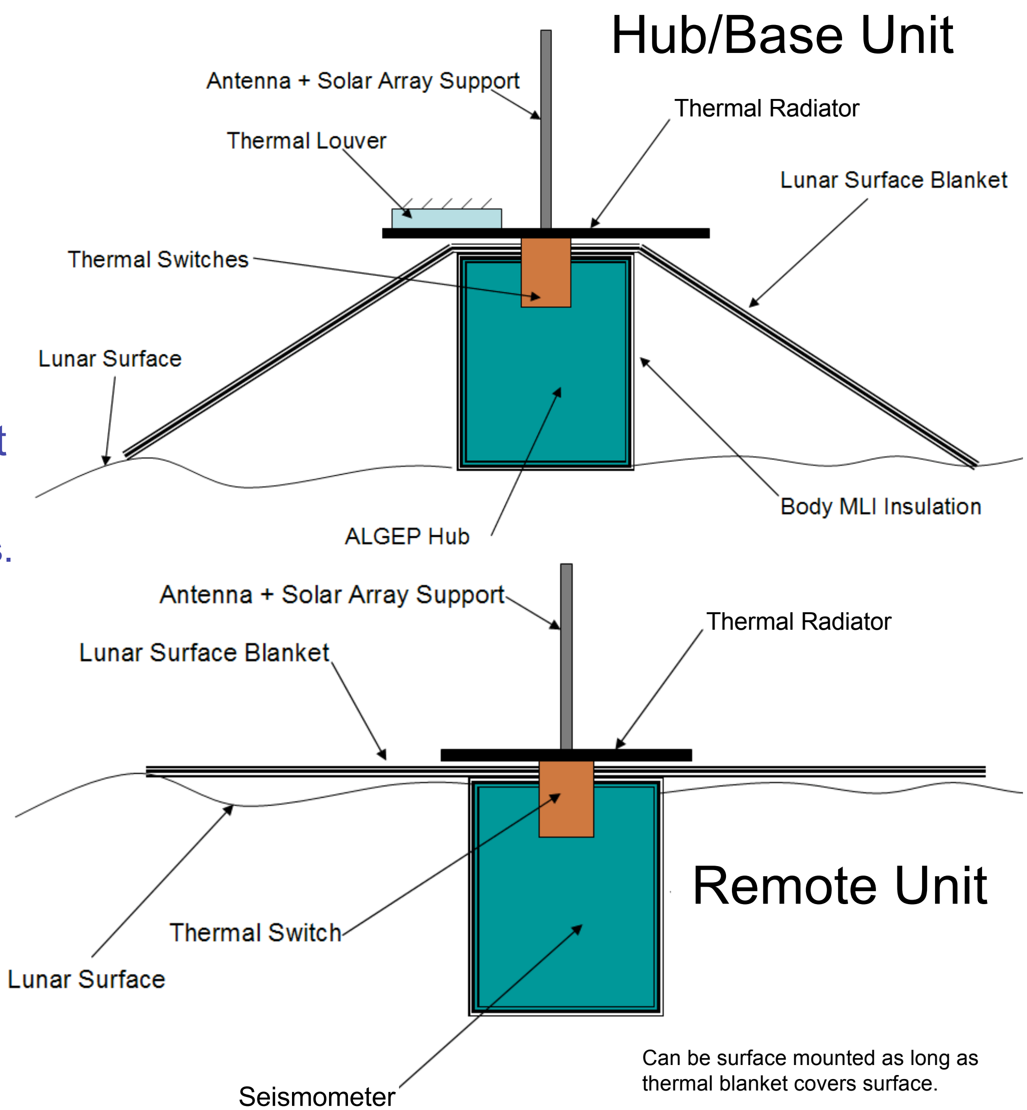
- Solar/battery power system
  - Low-power night operations mode
    - Only systems required for data acquisition are powered
  - Communication only during daylight
- Modular design
  - Hub/base module with CDS, telemetry
    - DTE communication
    - Instrument commanding, coordination and data collection via local UHF links
  - Independent instrument modules
    - Self-contained power, thermal, data acquisition
    - No physical links to base module
  - Independently deployed, minimal astronaut impact
    - Physical configuration is flexible
    - No cables to be managed

ALGEP Architecture Concept



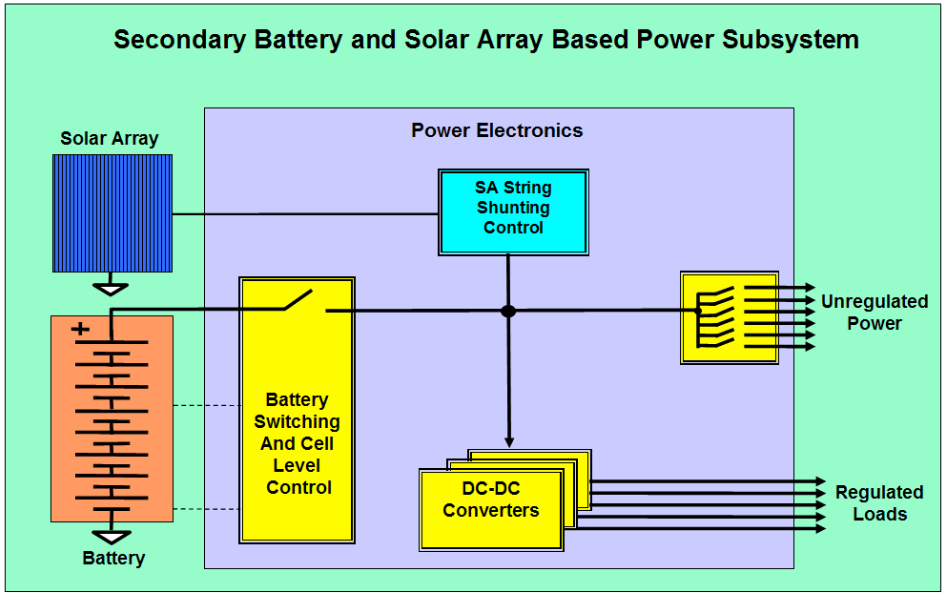
Thermal Subsystem

- MLI and lunar regolith thermal conduction are used to isolate ALGEP elements from excursions in thermal environment
  - Regolith sink at -50˚C
- Thermal blanket of Silver-Teflon used to moderate local temperature variation to -40 to -50°C
- Thermal switch and thermal radiator reject the internally generated thermal energy.
  - Thermal switch can transfer up to 11 Watts.
  - Hub may require multiple switches depending on the RF power output.
- Include small electric heater/thermostat system on the order of 10% of the dissipated electrical energy
  - For example, seismometer may require a 150 mW heater.
- Resulting operating temperature of -20°C to +35°C



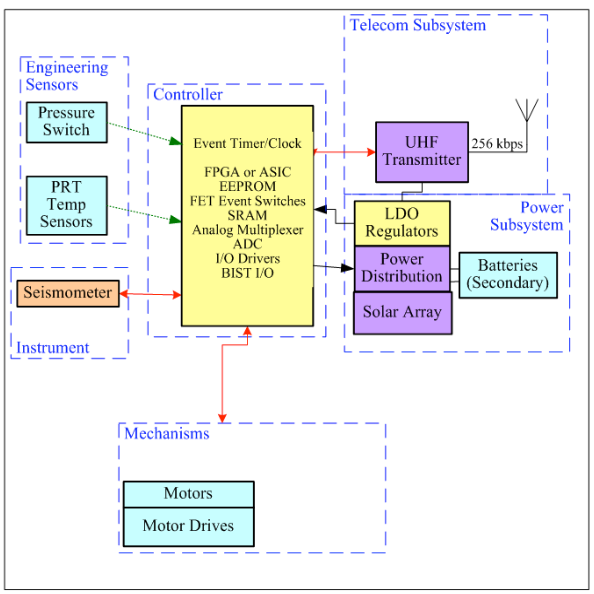
Power Subsystem

- Solar Array
  - Area of ~0.5 square meters
  - Small fold out or roll out blanket array; possibly umbrella mechanism
- Rechargeable Lithium-Ion Battery
  - Supports ~770 WH during night
  - Sizing to ~1500 WH for DOD & lifetime considerations
  - Dedicated timer battery
  - Volume: ~ 4 L
- Power Electronics
  - Power control via string switching and a small shunt regulator
  - Central power converter unit for end user load regulation
  - Load switching is done by inhibiting DC to DC converters or FET switches
  - Volume: ~0.5 L
- Hub/Base Unit is solar-only

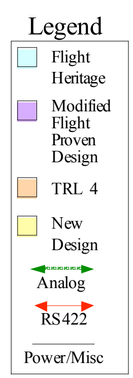


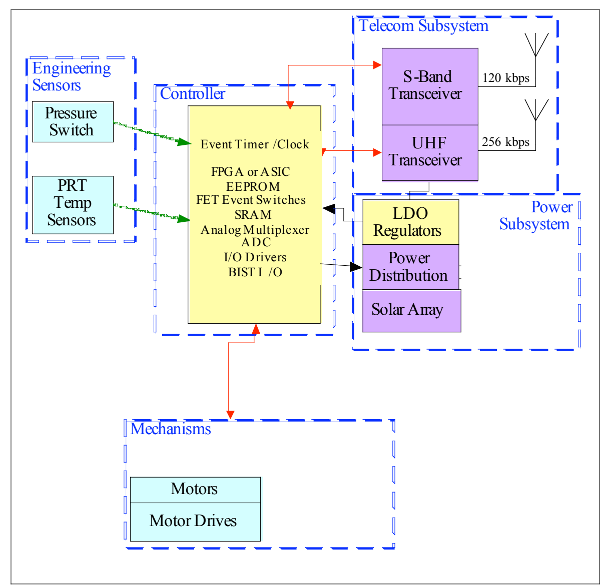
Command and Data Subsystem

- Controller interfaces to any of the four science instrument remote units
  - Remote units contain 2 Gbits storage
- Controller for hub/base unit requires larger SRAM to accumlate data from all instruments
  - Hub/base unit contains 5 Gbits storage
- Controller operating temperature range -40°C to +35°C
  - Custom design of electronic parts
- Data compression varies per instrument, with maximum of 2.5 for seismometer



Remote Unit Example





Hub/Base Unit

Telecom Subsystem

- Data Volume:
  - 3.4 Gbits of stored data every 14 days (night)
  - 1.2 Gbits of collected data each day while in sunlight
  - Translates to a minimum DTE rate of ~50 kbps over one 8-hour pass/day for 14 days
- DTE link is S-Band at 120 kbps to a DSN 34 m ground station
  - > 100% margin
- UHF cross-links from remote units to hub will utilize small, low power UHF transceiver for two-way communication at 128 kbps
  - Units are under development for the Mars program

Daylight Operations

- Science + Telecom in Daylight Operations Mode
- Data is accumulated over 1 Earth day
- Hub/base unit polls each of the remote unit separately at a designated interval for the data stored with the UHF telecom system.
  - Requires ~1 hr at 128 kbps.
- Hub/base unit then sends data back to Earth directly using S-band telecom system.
  - Requires maximum of 8 hours at 50 kbps each day using the DSN 34 m antennas.

Hub Mass Memory Required (Mbits)	1167.4	Hub equipped with 5 Gbits

Science Instrument or Engineering Interface	Compressed Data Storage (Mbits)	Description/Comments
Seismometer	404.4	Worst case, Per Earth Day, sunlight, 30% margin on raw data storage
Magnetometer	57.5	Worst case, Per Earth Day, sunlight, 30% margin on raw data storage
Heat Flow Probes	1.7	Worst case, Per Earth Day, sunlight, 30% margin on raw data storage
Seismic Sounder (High frequency)	688.2	Worst case, Per Earth Day, sunlight, 30% margin on raw data storage
Seismic Sounder (Low frequency)	10.0	Engineering Data from 4 active instruments
Instrument Engineering Data Total	4.5	Engineering Data from 4 active instruments
Hub Engineering Data	1.1	Engineering Data from hub

Night Operations

- Only data acquisition in Night Operations Mode.
- Data is accumulated over ~14 days.
- Magnetometer and Seismometer are acquiring data continuously, with seismometer at a reduced data rate (~4 kbps vs. 9 kbps).
  - Heat Flow Probe only takes temperature readings once per hour for 5 mins.
  - Seismic Sounder is not in operation.
- No UHF or S-band communication planned during night.

Hub Mass Memory Required	3388.3	Hub equipped with 5 Gbits
Science Instrument or Engineering Interface	**Compressed Data Storage (Mbits)**	**Description/Comments**
Seismometer	2516.0	Worst case, Per Earth Day, night, 30% margin on raw data storage
Magnetometer	805.1	Worst case, Per Earth Day, night, 30% margin on raw data storage
Heat Flow Probes	4.4	Worst case, Per Earth Day, night, 30% margin on raw data storage
Seismic Sounder	0.0	Worst case, Per Earth Day, night--not expected to be on at night, 30% margin on raw data storage,
Instrument Engineering Data	47.2	Engineering data from 3 active instruments
Hub Engineering Data	15.7	Engineering data from hub

Package Mass & Power Summary

Hub/Base Unit	Mass	Power
Power	1.0 - 2.0 kg	0.050 W / 2 W (Night/Day)
Thermal	5.0 - 6.0 kg	0 W
Telecom UHF Telecom S-band	0.5 – 0.75 kg 3.5 – 4.5 kg	3 W 40 W
CDS	0.7 - 1.5 kg	3 W
Structure	4.0 - 6.0 kg	0 W
Total	15 – 21 kg	48 W

Remote Unit	Mass	Power
Power	4.0 – 9.0 kg	0.050 W / 2 W (Night/Day)
Thermal	3.0 - 4.0 kg	10% instrument power
Telecom UHF	0.5 – 0.75 kg	3 W
CDS	1.0 -1.5 kg	3 W
Structure	1.0 - 5.0 kg	0 W
Total	10 kg – 20 kg	8 W

Estimated mass of complete package, including instruments:

75 to 125 kg

Conclusion

- We have developed a viable concept for the deployment of a geophysical station on the Moon by astronauts.
  - Modular architecture with independent instrument modules; Base unit acts as coordinator/relay station
  - Nuclear power is NOT required. Continuous operation of low-power instruments can be achieved using solar power/batteries alone.
  - Mass of entire package is of order 100 kg
- Remaining work:
  - Refine resource numbers at subsystem level
    - Mass, power, data storage, telecom
  - Determine a projected cost for the package, including operations
  - Iterate science requirements with science team
  - Investigate robotic deployment options